Dynamics of Boundary Currents and Marginal Seas

William E. Johns
University of Miami
RSMAS/MPO
4600 Rickenbacker Causeway
Miami, Florida 33149-1098
Phone: (305)361-4054 Fax: (305)361-4696 email:: wjohns@rsmas.miami.edu

Award Number: N0014-03-1-0319

LONG TERM GOALS

The long-term goals of this research are to understand the dynamics of ocean circulation near continental margins, with emphasis on western boundary current systems and circulation and exchange processes in marginal seas.

OBJECTIVES

Research during the past year has been focused on studies of the marginal seas of the northwestern Indian Ocean: the Red Sea and the Arabian (Persian) Gulf. Our objective has been to use recent field measurements and modeling studies to understand the exchange dynamics between these marginal seas and the Indian Ocean, including the variability in the connecting straits, and to study their general circulation and air-sea interaction budgets.

APPROACH

Measurements collected in these programs have consisted of moored time series observations of currents using profiling (ADCP) and conventional current meters, and water properties using temperature/salinity chain arrays, along with seasonal hydrographic surveys and local meteorological and tide gauge measurements. Modeling efforts include the application of analytical models for study of atmospherically forced fluctuations in the straits and regional numerical simulations with the Miami Isopycnal Coordinate Model (MICOM) to study the combined buoyancy and wind forced circulations and exchanges in the marginal seas.

WORK COMPLETED

1. Final data processing was completed from the new survey of the Red Sea conducted aboard the R/V Maurice Ewing in August 2001. The cruise was successful and it provided an excellent data set documenting the summer conditions in the Red Sea, including a shipboard ADCP survey, hydrographic/lowered-ADCP station data, and marine meteorological data and surface fluxes.

2. Final estimates of exchange through the Strait of Hormuz and the associated surface heat and freshwater fluxes over the Arabian Gulf were produced from in-situ data collected in the Strait of Hormuz, allowing a critical evaluation of available surface flux products for this basin (Johns et al., 2003). The flux constraints provided by the in-situ data revealed important biases in several of the

surface flux terms and is leading to improved parameterizations and treatments of these fluxes for the regional atmospheric conditions.

3. Extended MICOM modeling studies were performed for the Red Sea and Gulf of Aden region which successfully reproduced the magnitude and seasonal cycle of the exchange at the Bab el Mandeb strait and tested the sensitivity of model results to uncertainties in forcing fields, horizontal grid resolution, and domain size.

4. Mooring and equipment preparations were completed for a new field study of the flow structure and variability in the Windward Passage in the northeastern Caribbean Sea, to be carried out starting in October, 2003.

RESULTS

The results from the Strait of Hormuz experiment have been used to estimate the annual mean deep outflow of water from the Arabian Gulf and the heat and freshwater budgets of the Gulf. From our measurements we have determined the annual mean deep outflow from the Gulf to be 0.15 Sv with associated heat and freshwater losses over the Gulf of approximately 10 W/m^2 and 1.7 m/yr, respectively. We have compared these flux estimates with independent estimates derived from available surface flux climatologies (COADS, SOC, NCEP). These comparisons have shown that there are large and systematic errors in most of the surface flux data sets over the Gulf, which are related mainly to errors in the shortwave/longwave radiation and latent heat fluxes (Johns et al., 2003). Similar results and flux biases were found for the Red Sea from flux constraints provided by the earlier Bab el Mandeb measurement program (Sofianos et al., 2002). Work with Simon Josey and colleagues at SOC has helped to develop corrections for the radiative fluxes that are applicable to these marginal seas areas, including account of aerosol loading and improvement of the longwave parameterization. We have also compared our results with initial surface flux estimates from mesoscale atmospheric model runs for the region by Dr. S. Chen of RSMAS, which suggest that the mesoscale model fluxes do not suffer from these same large biases.

As a follow-up to our extended model simulations of the Red Sea (Sofianos and Johns, 2002a,b), which brought forth a number of new ideas on Red Sea circulation dynamics and water mass formation, we conducted a 10 day cruise in the Red Sea during August 2001 on the R/V Maurice Ewing. This cruise was accomplished at little net cost above the ship time as it was done while underway to the Gulf of Aden as part of an NSF-sponsored study of the Red Sea Outflow plume, in which the P.I. was also involved (Figure 1). More than 90 CTD/LADCP stations were occupied along the axis of the Red Sea and on several cross sections in the northern and southern parts of the basin, including the area of the Hanish Sill in the Bab el Mandeb Strait and in the Gulf of Suez. Extremely high salinities (maximum observed value 42.63 psu) were recorded in the Gulf of Suez (Figure 2a), decreasing from the head to the mouth of the Gulf. The temperature and salinity stratification results in a density pattern that is indicative of dense water formation and outflow from the Gulf. Twenty deep stations were occupied along the main axis of the Red Sea to determine the large-scale meridional stratification in the basin (Fig 2b). As expected, a strong signal was found of the relatively cold and fresh Gulf of Aden Intermediate Water, centered at about 60 m in the southern part of the basin and spreading to the north (undergoing strong mixing into the surface

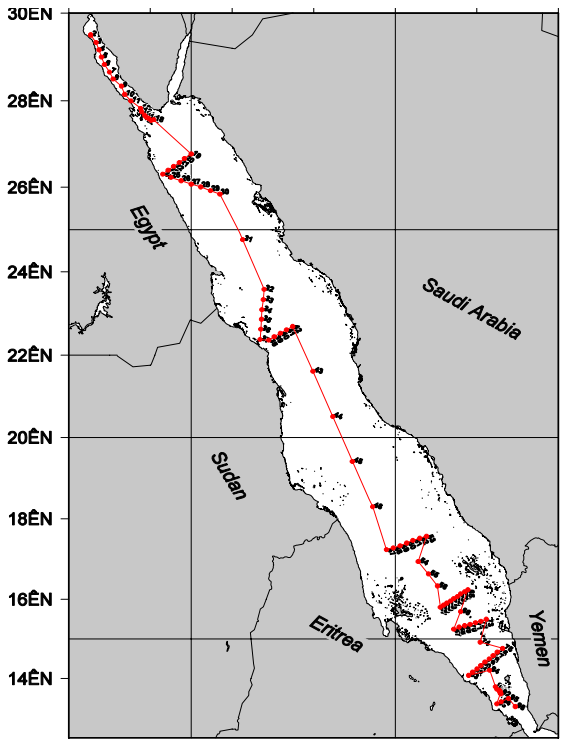

Figure 1. Cruise track and stations for the summer 2001 Red Sea cruise.

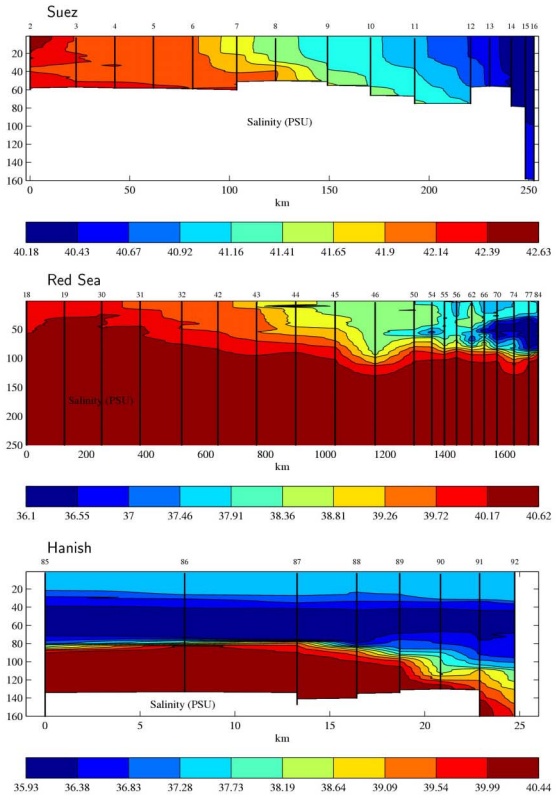

Figure 2. Salinity cross-sections from the August 2001 Red Sea cruise: (a) Gulf of Suez; (b) Red Sea (along central axis); (c) Bab el Mandeb at the Hanish Sill.

layer at the same time), reaching to a latitude of 18 N. The 3-layer exchange was also well established in the strait, including what appeared to be an unusually strong deep RSW outflow for the summer season (Fig 2c). Evidence for relatively strong gyres or eddies in the central part of the basin was indicated by the hydrographic and shipboard ADCP data (not shown), and a tight cyclonic gyre was found in the northern part of the basin in agreement with model predictions.

IMPACT/APPLICATIONS

The observations we have collected in this region have provided the first detailed, long-term time series observations in the Strait of Hormuz, as well as in the Bab el Mandeb Strait, both of which are strategically important straits, and new data on the summer circulation and hydrography of the Red Sea. These data are providing a new level of understanding of the circulation and exchange processes in these marginal seas and the associated dynamics. Comparative studies with other marginal seas and straits (e.g., Gibraltar) will help to improve and broaden our understanding of the dynamical controls regulating ocean-marginal sea exchange. The heat and freshwater transports determined from these measurements are providing important constraints on air-sea fluxes in these regions to help eliminate biases in existing climatologies and operational products.

TRANSITIONS

None

RELATED PROJECTS

Analysis of the Strait of Hormuz and Arabian Gulf data was carried out in collaboration with U.K investigators David Smeed and Simon Josey of the Southampton Oceanography Centre, who performed extensive shipboard surveys in the strait region during the period of the moored deployments and are developing improved surface flux climatologies for the region. We are also working with Dr. Amy Bower and Steve Swift of Woods Hole to investigate the hydrography and circulation in the Arabian Gulf in relation to the Strait of Hormuz exchange, and the characteristics of the outflow plume from the Gulf. The recent Red Sea study will share data and results with a related NSF study by the P.I. (in collaboration with H. Peters of RSMAS and A. Bower and D. Fratantoni of WHOI) on the dynamics and spreading of the Red Sea outflow in the Gulf of Aden. Measurements from the NSF-sponsored Red Sea Outflow plume study are also being compared to results from ultra high-resolution, nonhydrostatic model simulations of dense outflow plumes by ONR P.I. T. Ozgokmen of RSMAS.

REFERENCES

Sofianos, S., W. E. Johns, and S. P. Murray, 2002. The heat and freshwater budgets of the Red Sea from direct observations at Bab el Mandeb. *Deep-Sea Res. II*, 49, 1323-1340.

Sofianos, S. and W. E. Johns, 2002. An OGCM investigation of the Red Sea circulation. Part I: The Exchange between the Red Sea and the Indian Ocean. *J. Geophys. Res.*, 107, 3196, 10.1029/2001JC001184.

Sofianos, S. and W. E. Johns, 2002. An OGCM investigation of the Red Sea circulation. Part II: The three-dimensional circulation in the Red Sea. *J. Geophys. Res.*, 108, 3066, 10.1029/2001JC001185.

Johns, W. E., F. Yao, D. B. Olsen, S. A. Josey, J. P. Grist, and D. A. Smeed, 2003. Observations of seasonal exchange through the Straits of Hormuz and the inferred heat and freshwater budgets of the Persian Gulf. *J. Geophys. Res.* (in press).

PUBLICATIONS

Johns, W. E., F. Yao, D. B. Olsen, S. A. Josey, J. P. Grist, and D. A. Smeed, 2003. Observations of seasonal exchange through the Straits of Hormuz and the inferred heat and freshwater budgets of the Persian Gulf. *J. Geophys. Res.* (in press).

Ozgokmen, T. M., W. E. Johns, H. Peters, and S. Matt, 2003. Turbulent mixing in the Red Sea outflow plume from a high-resolution nonhydrostatic model. *J. Phys. Oceanogr.*, 33, 1846-1869.

PATENTS

None.